

Spectral Analyses Of The Hottest White Dwarfs: Grids Of Spectral Energy Distributions For Extremely Hot, Compact Stars In The Framework Of The Virtual Observatory

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Abstract

Present X-ray missions like *Chandra* and XMM-*Newton* provide high-resolution and high-S/N observations of extremely hot white dwarfs, e.g. burst spectra of novae. Their analysis requires adequate Non-LTE model atmospheres.

The Tübingen Non-LTE Model-Atmosphere Package *TMAP* can calculate such model atmospheres and spectral energy distributions at a high level of sophistication.

In the framework of the Virtual Observatory, the German Astrophysical Virtual Observatory (*GAVO*) offers *TheoSSA*, a *Virtual Observatory* (*VO*) service that provides easy access to theoretical SEDs.

We present a new grid of SEDs, that is calculated in the parameter range of novae and supersoft X-ray sources.

1. Introduction

In the last two decades, the Tübingen Non-LTE Model-Atmosphere Package (*TMAP**, [1, 2]) was successfully employed to perform spectral analyses of hot, compact stars based on observations from the infrared to the X-ray wavelength range (see, e.g. [3, 4]).

Many identifications of until then unidentified lines and subsequent determinations of the respective element abundances in recent years, that were based on high-resolution and high-S/N observations obtained with *FUSE*[†] and HST/*STIS*[‡] (e.g. Ne VII [5], F VI [6], Ar VII [7], Ne VIII [8], Ca X [9], and Fe X [10]), are the direct consequence of a continuous improvement of the *TMAP* code and its input atomic data.

TMAP Non-LTE models also provide SEDs for hot, compact stars. One important application are theoretical ionizing stellar fluxes, that are a necessary input for state-of-the-art photoionization models of nebulae, like the 3-D code *MOCASSIN* [11] and *CLOUDY* [12]. Both are able to deal with standard *TMAP* flux tables. However, the way into the 21st century, i.e. towards the use of reliable theoretical SEDs, e.g. in the planetary-nebulae community, was long – and still there is a temptation to use the “so-easy-to-calculate” blackbodies, that are of course only a very coarse approximation of any star. The blackbody flux maximum is in general at lower energy compared to a stellar spectrum of the same effective temperature (T_{eff}) and their peak intensity is lower [13, 14]. We describe how easy it is today to retrieve Non-LTE SEDs via the *VO* service *TheoSSA* in Sect. 3.

*<http://astro.uni-tuebingen.de/~rauch/TMAP/TMAP.html>

[†]Far Ultraviolet Spectroscopic Explorer

[‡]Space Telescope Imaging Spectrograph

TMAP can, in general, calculate models up to T_{eff} of about 10 MK. In applications to novae [15], *TMAP* still lacks some physics, most notably the velocity fields. However, it is a flexible and robust tool for the determination of basic parameters like T_{eff} , for line identifications [16], and to derive a reliable range of abundances in the white-dwarf atmosphere. We briefly describe *TMAP* and the atomic data that was considered for the model-atmosphere calculation in Sect. 2.

2. *TMAP* Non-LTE Models And Atomic Data

TMAP is capable to calculate plane-parallel and spherical, chemically homogeneous Non-LTE model atmospheres in radiative and hydrostatic equilibrium. It considers opacities of all species from hydrogen to nickel. Many studies (Sect. 1.) have shown that *TMAP* is a proven tool in spectral analysis of optical, UV, and X-ray [17].

The main limitation that we encounter now is the lack of reliable atomic and line-broadening data. Going to higher resolution and S/N in the observations reveals uncertainties in atomic data even for the most abundant species. There are always unidentified lines in UV observations [3], that most likely stem from highly ionized light metals like e.g. neon or magnesium.

In the framework of *GAVO*, we have set up the Tübingen Model-Atom Database (*TMAD*[§]). It contains ready-to-use model atoms in the *TMAP* format, that comprise most recent atomic data. For illustration, Fig. 1 shows the complexity of our neon model atom. The *TMAD* model atoms may be used by any other model-atmosphere code – provided that a suitable interface exists.

Within our recent analysis of the compact component in nova V4743 Sgr [15], we calculated extended grids of model atmospheres with $T_{\text{eff}} = 0.45 - 1.05$ MK and $\Delta T_{\text{eff}} = 0.01$ MK and $\log g = 9$. The presently available abundances are summarized in Tab. 1. See [15] as an example of the application of these grids for spectral analyses. Similar grids with lower $\log g$ are currently calculated. All these grids are available now via *TheoSSA* (Sect. 3), and, already converted to *atables*[¶] for the use with *XSPEC*^{||}. As an example, Fig. 2 shows SEDs from model grid 003.

3. *TheoSSA* – Theoretical Stellar Spectra On Demand

In the framework of the *VO*[†], *TheoSSA*[‡] is a registered service, provided by *GAVO*[§]. SEDs are easily accessible in *VO* compliant form via the *TheoSSA* WWW interface[¶]. The SEDs are available at three levels:

1) *fast and easy*: pre-calculated SED grids that span generally over a wide range of T_{eff} (50 – 190 kK) and surface gravity ($\log g = 5 - 9$) for different chemical compositions, e.g., pure H, pure He, H+He, He+C+N+O, C+O+Ne+Mg, H – Ca [13], and H – Ni [14].

2) *individual*: model atmospheres based on standard model atoms – neither profound knowledge of theory nor experience with the software is here a prerequisite. The photospheric parameters T_{eff} , $\log g$, and mass fractions $\{X_i\}$ for $i \in [\text{H}, \text{He}, \text{C}, \text{N}, \text{O}]$ can be adjusted in order to improve the fit to the observation. This is performed via *TMAW*, a WWW service within *TheoSSA*.

3) *experienced*: observers and theoreticians, who want to compare e.g. their own simulations with results of *TMAP*, the creation and upload of own atomic-data

[§]<http://astro.uni-tuebingen.de/~TMAD/TMAD.html>

[¶]http://astro.uni-tuebingen.de/~rauch/TMAF/flux_HHeCNONeMgSiS_gen.html

^{||}<http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec>

[†]<http://www.ivoa.net>

[‡]Theoretical Simple Spectra Access

[§]<http://www.g-vo.org>

[¶]<http://vo.ari.uni-heidelberg.de/ssatr-0.01/TrSpectra.jsp?>

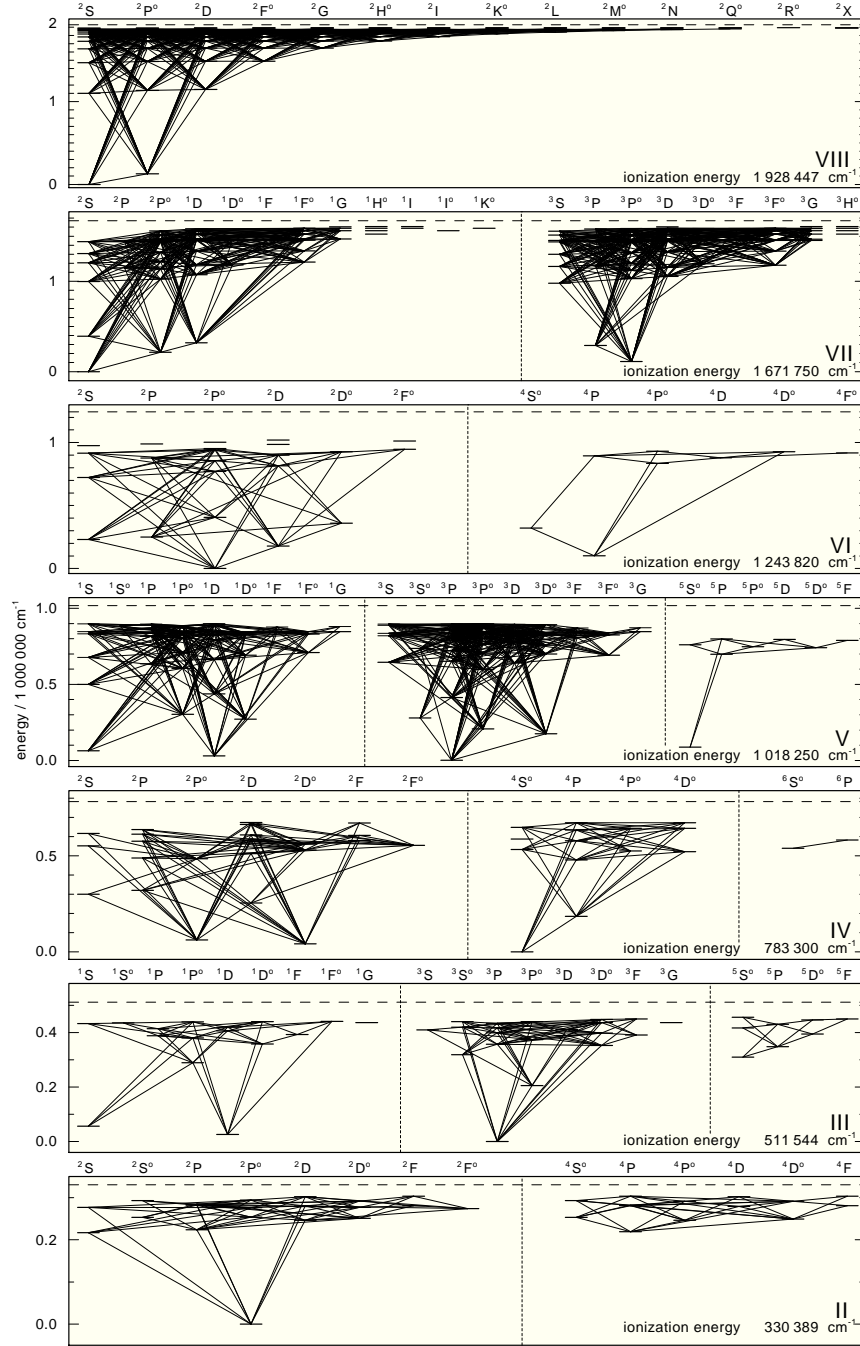


Fig. 1. Grotrian diagrams of the Ne III - VIII model ions that are provided by *TMAD*.

Table 1. Elements and their abundances (given as $\log [\text{abundance} / \text{solar abundance}]$, solar values from [18]) that are considered in our model grids (003 – 011). Fe is a generic model atom [2] that includes the elements Ca – Ni.

	003	004	005	006	007	008	009	010	011
H	-0.688	-0.683	-0.677	-0.673	-0.672	-0.671	-0.670	-0.670	-0.669
He	0.382	0.387	0.393	0.397	0.398	0.399	0.400	0.401	0.401
C	-1.513	-1.073	-0.772	-0.675	-0.596	-0.529	-0.471	-0.420	-0.374
N	1.803	1.678	1.460	1.159	1.062	0.937	0.761	0.460	0.159
O	1.528	1.533	1.538	1.543	1.544	1.544	1.545	1.546	1.547
Ne	-0.474	-0.469	-0.464	-0.459	-0.459	-0.458	-0.457	-0.456	-0.456
Mg	-0.454	-0.450	-0.444	-0.439	-0.439	-0.438	-0.437	-0.436	-0.436
Si	0.167	0.172	0.178	0.182	0.183	0.184	0.185	0.186	0.186
S	-1.583	-1.578	-1.573	-1.568	-1.567	-1.567	-1.566	-1.565	-1.565
Fe	0.828	0.833	0.838	0.843	0.843	0.844	0.845	0.846	0.846

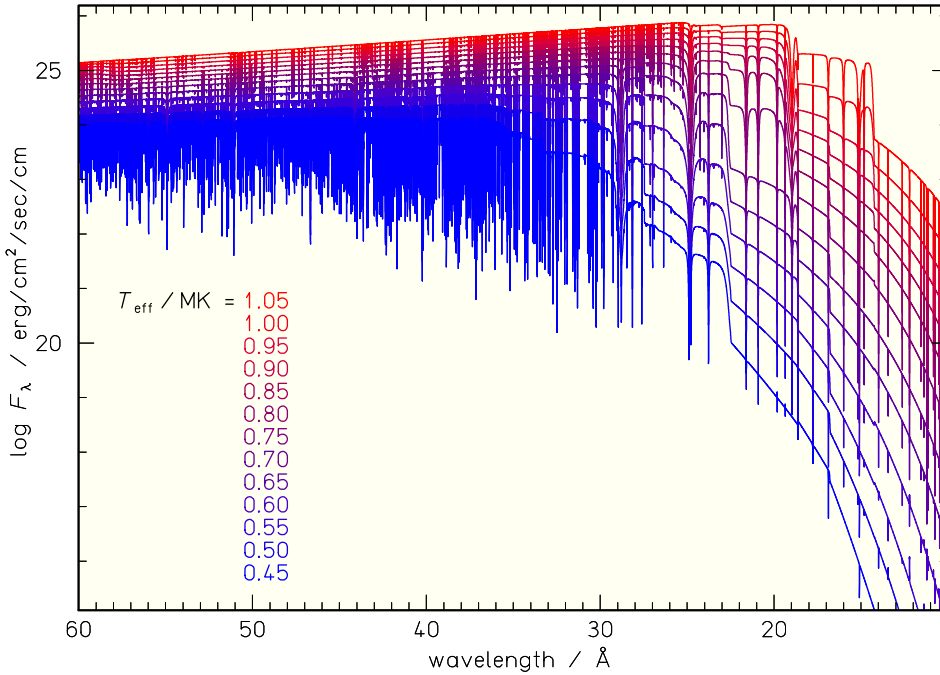


Fig. 2. Selected ($\Delta T_{\text{eff}} = 0.05$ MK) theoretical SEDs from model grid 003 (Tab. 1).

files is possible. *TMAD* provides model atoms which are suited for the use by TMAP. These may be adjusted for an individual object.

The usage of *TheoSSA* is simple (Fig. 3). A *VO* user submits a SED request to the *GAVO* database. If a suitable model is available within tolerance limits, this is offered. In case that the parameters are not exactly matched, the user may

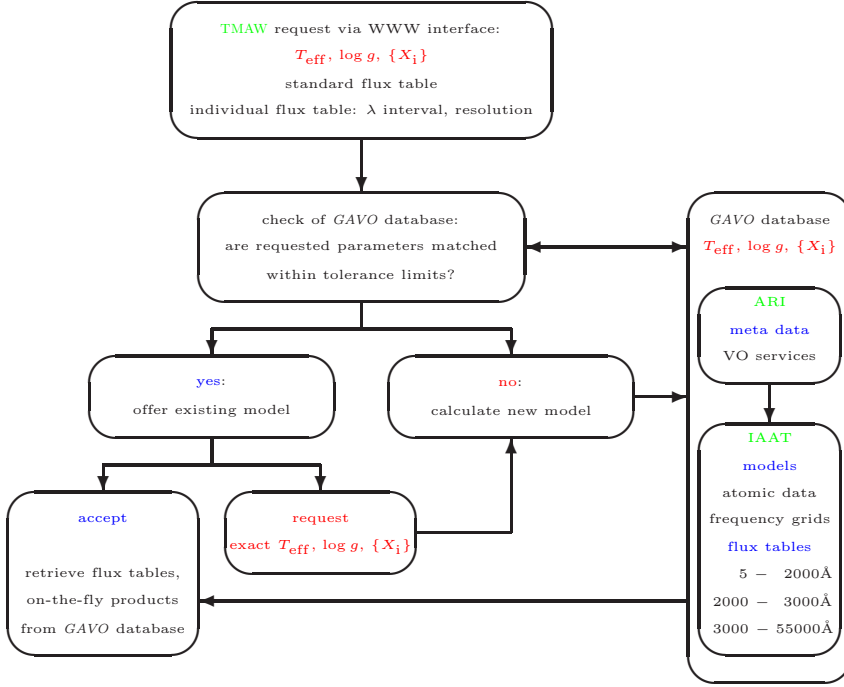


Fig. 3. Flow diagram of *TheoSSA*.

decide to request a model with the exact parameters. *TMAW* will start a model-atmosphere calculation at the IAAT then. As soon as the model is converged, the SED is automatically ingested in the *GAVO* database, that is growing in time in this way, and the user can retrieve the SED and various on-the-fly products from *TheoSSA*.

The calculation of a single H+He+C+N+O model needs about one day on a presently available 64 bit standard PC. For the calculation of extended model grids in reasonable time, *TheoSSA* makes use of compute resources provided by *AstroGrid-D*^{||}.

4. Conclusions

Theoretical spectral energy distributions for extremely hot, compact stars are available and to retrieve them via the *GAVO* service *TheoSSA* (Sect. 3.) is easy – use them!

Spectral analysis by means of Non-LTE model-atmosphere techniques has for a long time been regarded as a domain of specialists. With *TheoSSA*, the access to individually calculated SEDs is as simple as the use of pre-calculated SEDs – without detailed knowledge of the programme, that is calculating in the background. However, the user has to be aware of the impact of metal opacities on the flux in the high-energy range [13, 14, 15] and has to use appropriate SEDs for individual objects. In case of doubt or for any question, please do not hesitate to contact astro-tmaw@listserv.uni-tuebingen.de directly.

^{||}<http://www.gac-grid.de/>

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